Performance Characteristics of a Glow Plug Assisted Low Heat Rejection Diesel Engine Using Methanol as Fuel with Additives

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Abstract: The scarcity of transportation petroleum fuels due to the fast depletion of the petroleum deposits and frequent rise in their costs in the international market have spurred many efforts to find alternatives. Alcohols were quickly recognized as prime candidates to displace or replace high octane petroleum fuels. Innovative thinking led to find varies techniques by which alcohol can be used as fuel in diesel engine. Amongst the fuel alternative proposed, the most favourest ones are methanol and ethanol. The specific tendency of alcohols to ignite easily from a hot surface makes it suitable to ignite in a diesel engine by different methods. The advantage of this property of alcohols enables to design and construct a new type of engine called surface ignition engine. Methanol is very susceptible to surface ignition, this method is very suitable for this fuels. The hot surfaces which, can be used in surface ignition engine are electrically heated glow plug with hot surface engine and the further the engine is modified as Low heat rejection (LHR) engine. A Partially stabilized Zirconia is used as a thermal barrier coating to provide as a adiabatic engine. Hence the experiments are carried out on the normal engine on the copper piston crown material with additive (Iso amyl nitrate) on GHSI engine and in LHR engine using Ethanol as fuel to determine the performance, emissions and the combustion parameters.

Key word; Methanol; Iso amyl nitrate; Glow plug hot surface ignition (GHSI) Engine; low heat rejection (LHR) Engine;

I. INTRODUCTION

The conventional fuels like petrol and diesel are depleting at a tremendous rate. Other than this there is an increasing environmental pollution. These things have led for the encouragement of research in the development of alternative fuels and engine design. The Experimental works that have been carried out in the past have aimed at good fuel economy and lower tailpipe emissions. The depleting nature of fuel reserves, global warming and increasing cost of crude oil have caused increasing emissions. The smoke emissions are the growing concerns and questions are being asked about sustainable development. The present work is an attempt towards finding alternate fuels (Methanol and Ethanol) as a substitute over diesel in diesel engines to reduce diesel consumption. Another reason for the development of alternative fuel is the fact that huge percentage of crude-oil is imported from other countries that control oil fields. In the present scenario many alternate fuels are used in limited quantities in automobile engines.

1.1 Methanol: Methanol can be produced from Natural gas, coal, biomass, and urban waste. Most of the Methanol produced from Natural gas. In producing Methanol from Natural gas a considerable amount of the energy is lost. Thus, this process does not appear to offer a viable long-term solution to the alternative fuels problem. The production of Methanol from coal does have potential for the long-term even though there is an additional energy loss. Another disadvantage in producing Methanol made from coal is that the generation of carbon dioxide is greater than that for purifying and using gasoline. In spite of these disadvantages, the world assets of coal are many times greater than that of Natural gas and petroleum. Thus it is a potential energy source for meeting the nation's transportation needs for the future.

Methanol fuel is not well suited for use in unmodified compression Ignition (CI) engines. It has poor self-ignition characteristics; therefore, its use in Diesel engines requires a means for providing ignition. For single fuel engines this entails use of a spark plug or Glow plug, fuel additive ignition improvers, or enhanced auto – ignition through the use of exhaust gas recirculation. Several of the heavy –duty (Diesel) engine manufactures have developed Methanol engine derivatives of their Diesel engine lines [1].

1.2 **Surface ignition system**

Methyl alcohol and Ethyl alcohols can also be ignited in a Diesel in a Diesel engine with the help of surface ignition. In this type of ignition, the injected fuel ignites not by compression ignition but by contact with the hot surface maintained within the engine. Since Methanol and Ethanol are very susceptible to surface ignition {pre-ignition in SI engines), this method is suitable to these fuels. The hot surface ignition engine is reported to have better multi fuel capability than its spark assisted counterpart [2]. After careful review of introduction the present work is carried out on glow plug hot surface ignition engine with different piston materials, additives and LHR concept using alcohols as fuel with an objective to find the best one in terms of performance, combustion and emissions.

II. REVIEW OF LITERATURE

The specific tendency of the alcohols to ignite easily from a hot surface makes it suitable to ignite in a Diesel engine by different methods. The advantage of this property of alcohols enables us to design and construct a new type of engine called the surface ignition engine. The available literature can be broadly categorized into two as follows.

1. Use of Glow plugs as hot surfaces.
2. Use of specially constructed hot surfaces with large areas.

2.1 Use of Glow plugs as hot surfaces

This methods aims to solve the difficulty of auto ignition of alcohol fuel it can also provide 100% replacement of 100% diesel fuel. On the various fuels, Nanni et al [3] where the first to conduct the experiments successfully on a Glow plug hot surface ignition engine. Their tests revealed that for good part load performance with Methanol, the considerable amount of Glow plug energy input was necessary. The Glow plug power could be decreased or even turned off a full output with brake thermal efficiency better than normal Diesel values.

The best location for the Glow plug was noticed as a region of low turbulence with mixture sufficiently rich to cause ignition. It was observed that, the electric power consumption was 260W with Ethanol and gasoline, and about 180W with Methanol. They concluded that the ideal fuel is one with a low pre-ignition resistance and good anti-knock rating.

The Nanni et al [4] found that the ignition stage in the hot surface ignition engine was similar to Diesel combustion with ignition delay and rate of pressure rise close to Diesel values. The second stage was like Otto combustion involving flame propagation. The two stages combined together cause the increase of Glow plug energy input. The advance of the injection timing improves the part load performance. The combustion and flame propagation could be improved at low loads by intake throttling to make the rich mixture. The best overall performance was obtained at a Glow plug temperature of 950^0C.

Noboru Miyamoto et al [5] have conducted the tests on Glow plug and spark plug assisted Diesel engines with fuels like Methanol and ethanol. They found that an increase in the Glow plug temperature resulted in inferior performance at full output. This was because of lengthening of the combustion duration and shortening of the ignition delay. With alcohols, NO_x emission was reduced. It was observed that even at a Glow plug temperature of 600^0C, the starting of the engine was satisfactory.

The experiments of Tadashi Muruyama et al [6] with Ethanol for good combustion revealed that the Glow plug has to be located in a stagnant zone without direct impingement of the fuel and that only the fuel vapour must touch the hot surface. At no load operation above 1200 rpm, combustion difficulties were noticed because of large temperature drop of the hot surface due to heat transfer to the relatively cold cylinder gases. The injection advance would be more critical than temperature of the Glow plug at high speeds. At low loads, the tests also indicated lower brake thermal efficiency, higher HC and un-burnt fuel and noise. It was found that, there was no difference in performance of the engine up to 10% water in Ethanol.

A temperature control system was built and experimented successfully by Nanni et al [7] in order to maintain the temperature of the Glow plug within the limits that will ensure good engine performance and Glow plug durability. The rapid heat release near Top Dead Centre (TDC) and lower gas temperature in the cycle are found to be the reasons for the high efficiency of the Methanol engines (both Glow plug type and carbureted spark ignition type).

The naturally aspirated Glow plug Methanol engine has been shown to have efficiency almost similar to the spark ignition carburetor type engine. Under turbo charged conditions, the Glow plug engine is said to have advantages due to lack of pre – ignition problems and ability to work with minimum or no electrical input with self- ignition of Methanol taking place.

A single cylinder water cooled Diesel engine was converted by Dinesh Kumar et al [8] to accommodate a 150W nominal rating Glow plug for ignition of Methanol. In order to obtain good performance, a Glow plug temperature of 800^0C and energy input of 180 to 270W was necessary. Initial sluggish combustion with Methanol necessitated the use of higher injection advances. In the lower load ranges, despite the high Glow plug inputs the brake thermal efficiency was lower than Diesel values. Though the peak pressure and rate of pressure rise were lower than with Diesel, which were lower than spark ignition engine values. The tests reveal that the lower NO_x emissions and higher HC and unburnt fuel emissions as compared to Diesel.

Pischinger et al [9] experiments were confined to reduce the unaffordable exhaust emissions at high heater inputs and at low loads. They have adapted the method of shielding the hot surface to reduce the heat losses, and aid mixture formation close to the Glow plug. On an average there was a reduction of about 50% of the Glow plug energy input by this method.

When the distance between the Glow plug and the injector was increased, the ignition delay was found to increase. A compression ratio of 18:2 was necessary to get good part load behavior with Methanol. The swirl level in the engine could be reduced because of the good mixture formation tendencies of Methanol.

For good low load operation, a temperature of 900^0C was recommended. The optimized configuration of engine produced NO_x levels equal to a third observed under Diesel operation while the HC and CO values were roughly the same. Sometimes the Aldehyde emissions were even lower than the Diesel operation.

According to D. Kumar et al [10] the performance was found to be effected considerably by the projection of Glow plug into the combustion chamber. When cast iron piston replaces the aluminum piston, it was found to improve the performance as a result of reduced heat losses. Partial insulation of combustion chamber causes the temperature of the Glow plug to go up by 60^0C for the same electrical input. An increase in compression ratio resulted in good performance with as low power consumption as 65W by the Glow plug, but was accompanied by higher cylinder pressures. At the optimum location of the Glow plug, the engine was 10% more efficient at hit loads and 20% less efficient at low loads than its Diesel counterpart.

K. Imoto et al [11] have conducted different tests by using Methanol as fuel to compare Glow plug assisted, spark assisted and pilot Diesel assisted pre chamber combustion systems. They have employed a ceramic Glow plug in the ignition system, and was found to ensure stability of ignition combustion upto high speed with good performance and low NO_x emissions. The Glow plug assisted system was found to be the best. The spark assisted system showed the highest combustion instability.

S.K. Singal et al [12] observed that the heat release rates of a Glow plug ignited Methanol engine revealed that the most of the injected fuel was burnt too early in the combustion process. This was due to the better mixture formation tendencies of Methanol. The combustion efficiency was found to be poor at light loads. Large nozzle whole diameters caused an increased ignition delay due to the higher rates of injection which cooled the cylinder gases. When the compression ratio was increased, it was found that, the peak heat release rate was also increased.

The main objectives of Cornelis Havenith et al [13] work were the high thermal efficiency, low exhaust emissions and good Glow plug durability, using Methanol as fuel. Their work was confined to surface temperatures ranging between 750^0C and 950^0C. They used the shielded ceramic Glow plugs along with a temperature controller which sensed exhaust temperature and engine speed as input variables. For best performance, the perforation size on the shield was 1mm and the projection was 17mm. in view of lubrication and cavitation problems, special attention was taken to modify the injection system. Successful field tests under city driving conditions were conducted upto 45000 km with good Glow plug durability. The NO_x emission was 1/3 to 1/2 of Diesel values. HC, CO and aldehyde emission levels were similar to Diesel engines, while peak pressure and rate of pressure size were lower.

Murayama et al [14 & 15] conducted different tests to know the suitability of spark assisted, hot surface and dual fuel methods to burn Methanol and Ethanol. The various factors which effect the combustion in the hot surface ignition engine were identified as amount of fuel, injection timing, Glow plug temperature and water content in the fuel. The best performance was observed by them when the Glow plug was located in a stagnant region. They have come to a conclusion that the Glow plug or the spark plug methods is the best for neat alcohol utilization. Between these two, the Glow plug method has better multi fuel capability.

According to Yui et al [16], the surface temperature of the Glow plug was found to have an effect on No_x, CO and HC emissions and Cyclic fluctuation of mean effective pressure. The distance between the Glow plug and nozzle was found to be very critical. This distance must be the shortest in order to have a maximum brake thermal efficiency and minimum fluctuation in mean effective pressure. Increase of the number of nozzle holes created a more uniform mixture in the cylinder, which results in higher brake thermal efficiency for good performance, the intake swirl had to be low at low loads.

Barnescu et al [17, 18& 19] converted Turbo charged Diesel engine for Glow plug assisted Methanol operation. Shielded ceramic Glow plugs were used in order to obtain good performance with Glow plug energies as low as 50W. The ignition delay was increased with Methanol. When the compression ratio was increased from 15.6 to 17.3, there was a reduction in HC and CO emissions. The engine could be operated without any electrical input to the Glow plug at high loads. The injection timing has to be retarded at high loads for low NO_x levels and advanced at low loads for low HC and CO emissions. At light and medium loads the overall performance was approximately similar to Diesel values, and was better than the Diesel at high loads.

C. Havenith et al [20] have selected an optimum surface temperature of 800^0C to 850^0C, for good performance of the shielded ceramic Glow plug Methanol engine. On maintaining the surface temperature at this optimum level, a control system was used. The Methanol engine was slightly less efficient than its Diesel engine. Transident tests showed higher brake specific energy consumption than the Diesel engine. Particulates were down by 70% and aldehyde emission (20 ppm) was double that of Diesel values. The poly cyclic aromatic hydrocarbon emission was $1/9^{th}$ that of Diesel engines.

At a Glow plug energy of 200W, Cu et al [21] observed good performance in a pre-chamber engine fuelled by Methanol. The advancing of injection timing and lowering of injection pressure was found necessary. They observed that the brake thermal efficiency was better than Diesel values at high loads and it was inferior at low loads.

III. EXPERIMENTAL WORK

In the present experimental work the single cylinder, four strokes 5.2kW Kirloskar, water-cooled DI diesel engine with a bore of 87.5 mm and stroke of 110 mm and a compression ratio of 17:1 is used. The engine load is applied with eddy current dynamometer. For the reduction of heat to the cooling water .the plain engine is modified as Glow plug hot surface ignition (GHSI)engine and further it fitting with a PSZ coated cylinder head and liner it is called Low heat rejection (LHR) engine.The photographic view of normal engine, GHSI engine and LHR Engines shown in below.

Figure1: Photographic view of Experimental Set up

Figure 2:shows the Sectional view of piston cylinder assembly showing the glow plug and fuel injector arrangements

Figure 3:Zirconium Oxide coated piston and head

It is established that the engine efficiency can be improved using the LHR concept.The development of advanced materials such as ceramics in the last 10 to 15 years has helped the researcher to progress towards the development of LHR engines.

The normal engine is modified by fitting with a PSZ coated cylinder head .Then the existing aluminum piston is replace by a copper crown piston. This air gap surface.These tests are conducted with Methanol as fuels in GHSI engines as usual.

The experiments are carried out on the normal engine with the copper piston crown material with or without additive (Iso amyl nitrate) on GHSI engine and in LHR engine using Methanol as fuel to determine the performance, emissions and the combustion parameters which are presented below.

IV. RESULTS AND DISCUSSIONS

4.1 Brake Thermal Efficiency

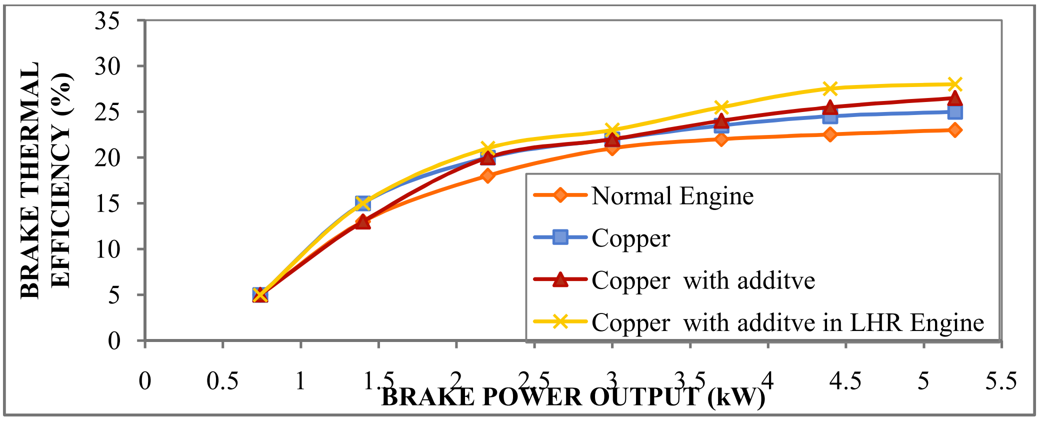

Figure 4: Variation of Brake thermal efficiency with power output for Iso-amyle Nitrate Fuel additives in Copper GHSI -LHR Engine

The variation of brake thermal efficiency with brake power output is illustrated in figure 4. The brake thermal efficiency of copper piston crown material GHSI with additive in LHR engine shows maximum efficiency over a wide range of operation. The brake thermal efficiencies of copper piston crown material GHSI engine with and without additive are found to be closely following the normal GHSI engine. The normal GHSI engine indicates minimum performance as compared to other above configurations. The percentage improvement for the copper piston crown material GHSI engine with additive in LHR engine over the normal engine is 6% at rated load. This is due to the positive ignition of the injected Methanol spray under all conditions. The improvement with Glow plug with copper piston crown material additive is multiplied by the ability of the LHR engine to prepare the injected Methanol spray into a readily combustible mixture within very short time. The hotter combustion chamber of the copper piston crown material GHSI with additive in LHR engine is instrumental in preparing the Methanol spray.

4.2 Brake Specific Fuel Consumption

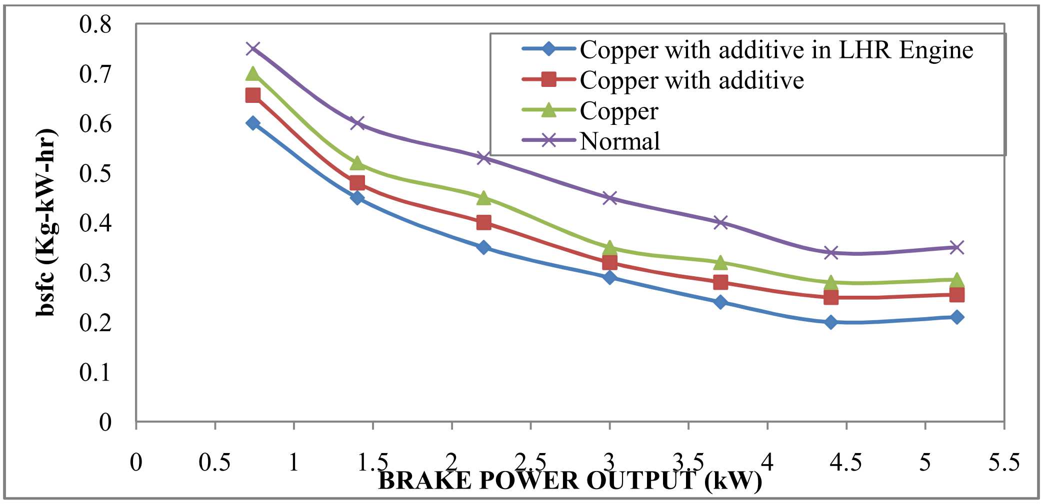

Figure 5: Variation of Brake Specific Fuel Consumption with power output for Iso-amyle Nitrate Fuel additives in Copper GHSI -LHR Engine

The variation of bsfc with power output is illustrated in figure 5. All the configurations GHSI LHR engine have lower brake specific fuel consumption compared to base engine. The Copper with additive in LHR engine gives lower bsfc over wide range of operation.The brake specific fuel consumption principally depends upon the consistent mixture formation and complete combustion of the fuel. With the better vaporization of the fuel, the charge becomes homogeneous and the combustion of fuel can be improved. The heat within the combustion chamber will increase and the combustion potency is improved. The rise in combustion potency provides fuel economy. The copper crown piston acts as a good heat reservoir, with its better thermal properties. This will increase the temperature of the incoming air and any the combustion potency.

4.3 Volumetric Efficiency

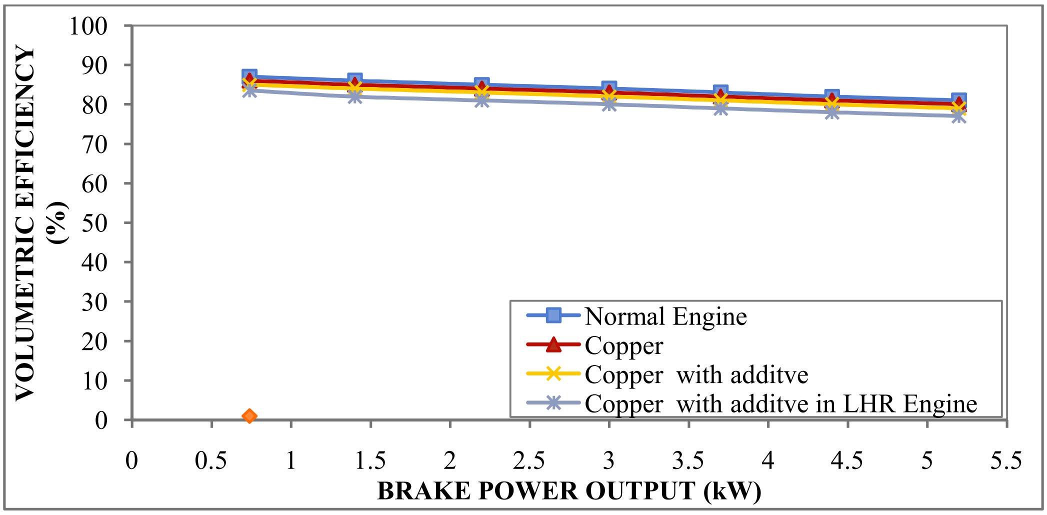

Figure 6: Variation of Volumetric efficiency with power output for Iso-amyle Nitrate Fuel additives in Copper GHSI -LHR Engine

The variation of volumetric efficiency with power output is illustrated in figure 6.The general trend is that the volumetric efficiency drops with increase in power output. At standard condition, the volumetric efficiency varies from 88% at no load to 85% at full load. With copper configuration the volumetric efficiency comes to 86% at no load and to 78% at full load.

The volumetric efficiency has a bearing on power output. Because of insulation, the combustion chamber surface temperature increases, and there will be more heat loss to incoming air, resulting in a drop in volumetric efficiency. Since the incoming air density suffers, the combustion phenomenon is also affected. Therefore in insulated Engines, the drop in volumetric efficiency is a major problem. The drop in volumetric efficiency can be compensated by supercharging or by turbocharging.

4.4 Hydrocarbons

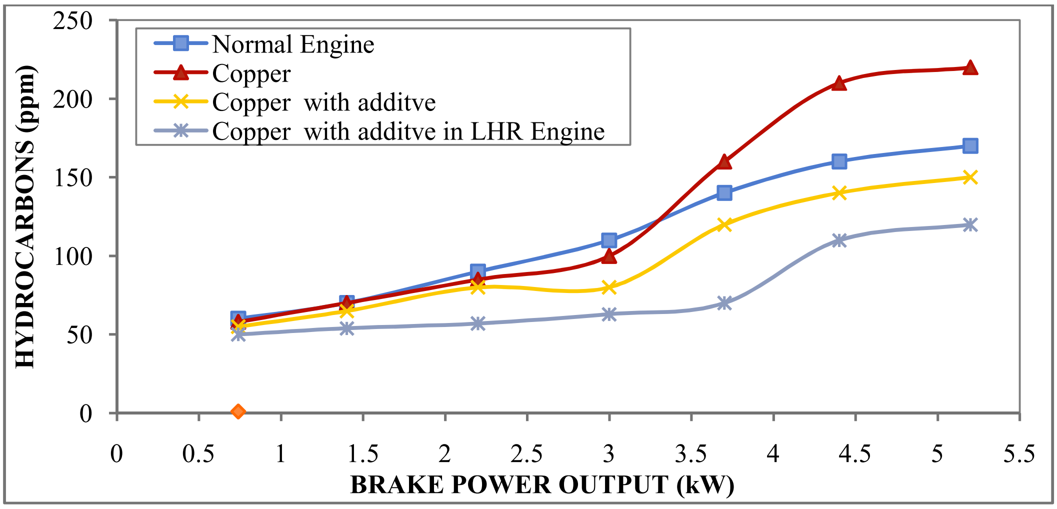

Figure 7: Variation of Hydrocarbon Emissions with power output for Iso-amyle Nitrate Fuel additives in Copper GHSI -LHR Engine

The HC emission levels for normal GHSI engine and copper piston crown material with additive in GHSI and in LHR engines are shown in figure 7. It is observed that the copperpiston crown material GHSI with additive in LHR engine shows a maximum reduction in HC emission level when compared to normal GHSI engine. The reduction in HC emission level over the corresponding normal GHSI engine is about 115 ppm at the rated load.

4.5Carbon dioxide Emission

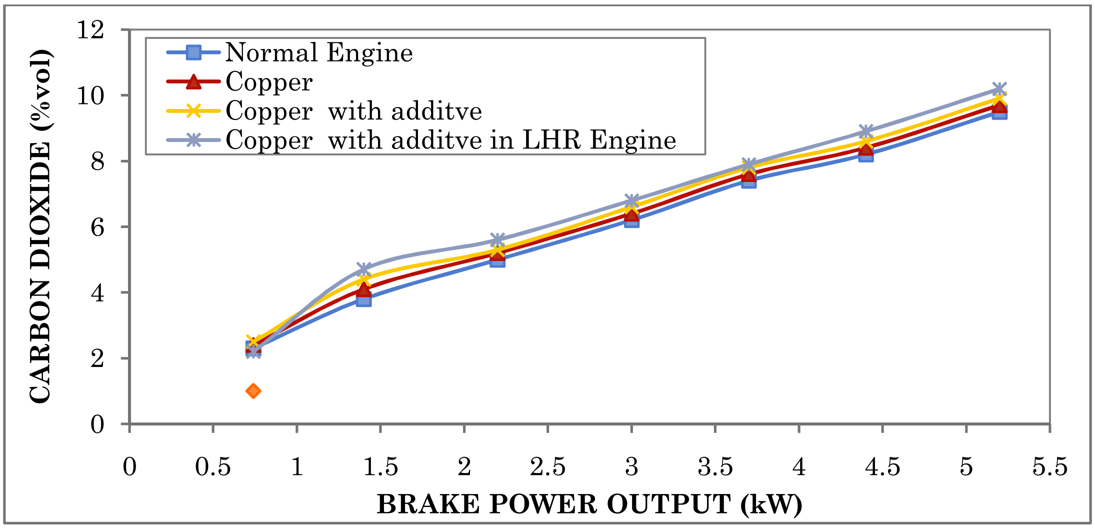

Figure 8: Variation of Carbon dioxide with power output for Iso-amyle Nitrate Fuel additive in Copper GHSI -LHR Engine.

The variation of carbon dioxide emissions with power output is illustrated in figure 8. Because of better and complete combustion in the insulated engines, Carbon dioxide levels are higher for insulated engines. It indicates that the level of Carbon dioxide in the exhaust is highest for Copper piston crown configuration. Higher Carbon dioxide in the exhaust is an indication of complete or better combustion.

4.6 Carbon Monoxide Emission

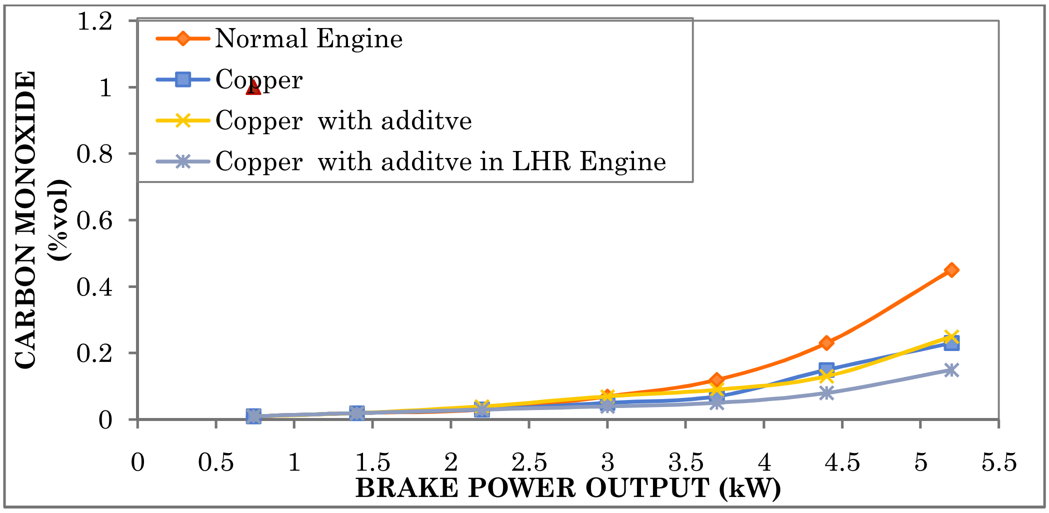

Figure9: Variation of CO emission with power outputfor Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

Figure 9.Shows the variation of CO with power output. The copper coating GHSI with additive in LHR engine indicates the lower level of CO emissions when compared to the normal GHSI engine and about 7% by volume at rated load. The reeducation is more pronounced at rated loads than at part loads.

4.7 Nitrogen Oxide Emissions

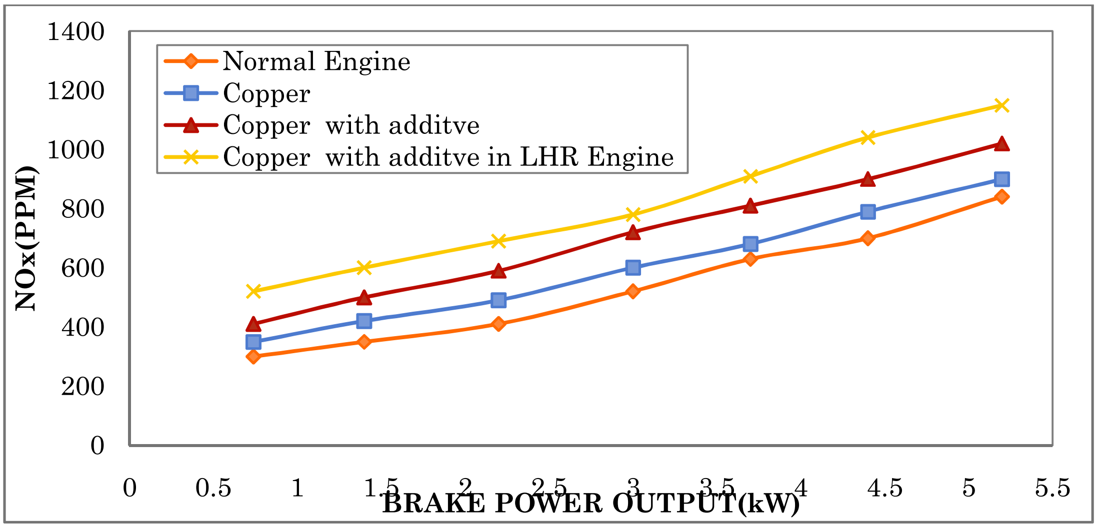

Figure10:Variation of NOx emission with power output for Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

The variation of nitrogen oxide emissions with power output is illustrated in figure 10. Because of better and complete combustion in the insulated engines, Nitrogen oxide levels are higher for insulated engines. It indicates that the level of nitrogen oxide is highest for Copper GHSI configuration. Higher nitrogen oxide in the exhaust is an indication of complete or better combustion

4.8 Exhaust Gas Temperature

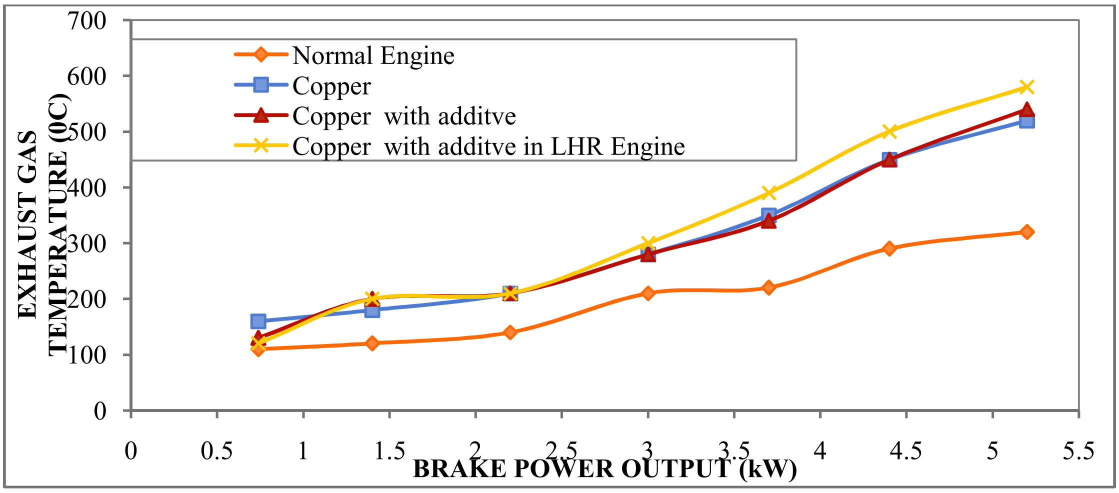

Figure 11:Variation of Exhaust gas temperature with power output for Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

The variation of exhaust gas temperature with power output is illustrated in figure 11. It clearly indicates that with the degree of insulation increasing the exhaust gas temperature progressively increases. Exhaust temperatures increase with the engine load. Because of better insulation for the Copper GHSI configuration, the exhaust temperature is higher compared to all other configurations. There is a 215^{0}C rise in the exhaust temperature for this configurations compared to base engine.

4.9 Ignition Delay

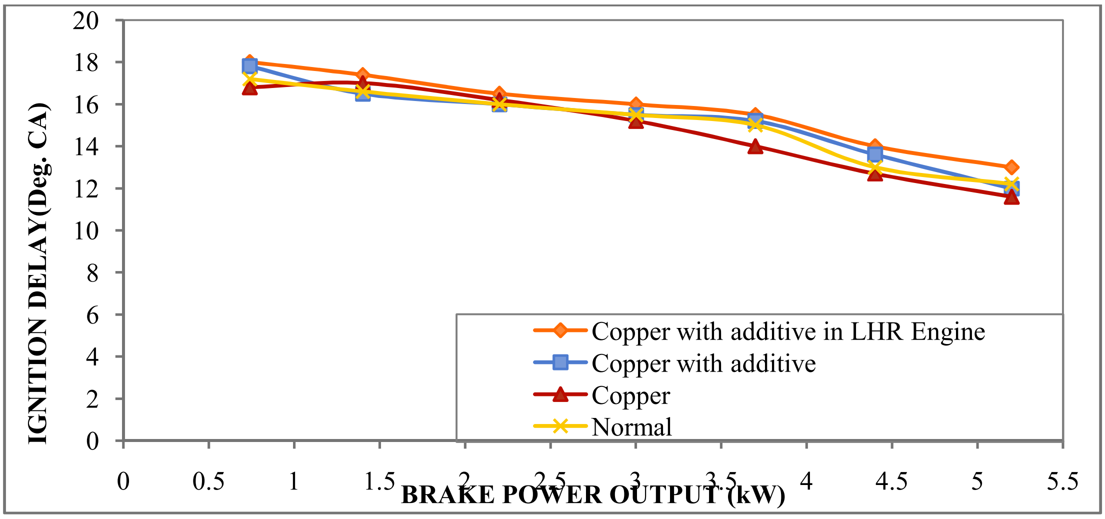

Figure12:Variation of Ignition delay with power output for Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

Figure 12 illustrates the variation of ignition delay with brake power output. The ignition delay is observed to be highest for the normal GHSI engine. The reduction in ignition delay for copper piston crown material GHSI with additive in LHR engine over normal GHSI engine is about 3.2^{0}CA. This is due to hotter combustion chamber of the LHR engine. Therefore the operation of LHR engine is smothering as compared to the normal engine.

4.10 Indicated Mean Effective Pressure

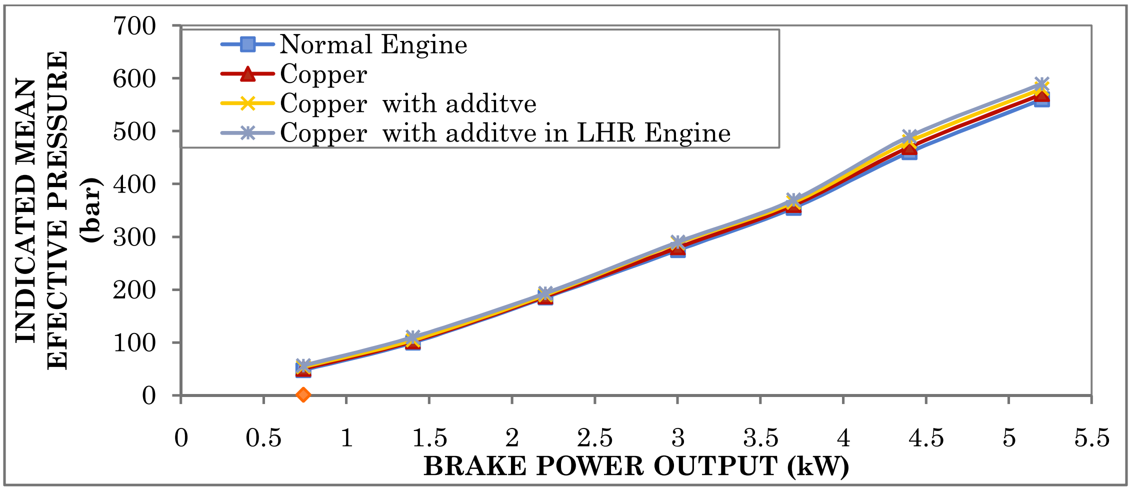

Figure13 Variation of Indicated mean effective pressure with power output for Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

The variation of indicated mean effective pressure with power output is illustrated in figure 13. The increase in the Indicated mean effective pressure is normally expected because of higher temperatures in these configurations. Highest Indicated mean effective pressure is obtained for the Copper GHSI configuration compared to other configurations. The increase in the Indicated mean effective pressure depends upon the level of insulation applied.

4.11 Peak Pressure

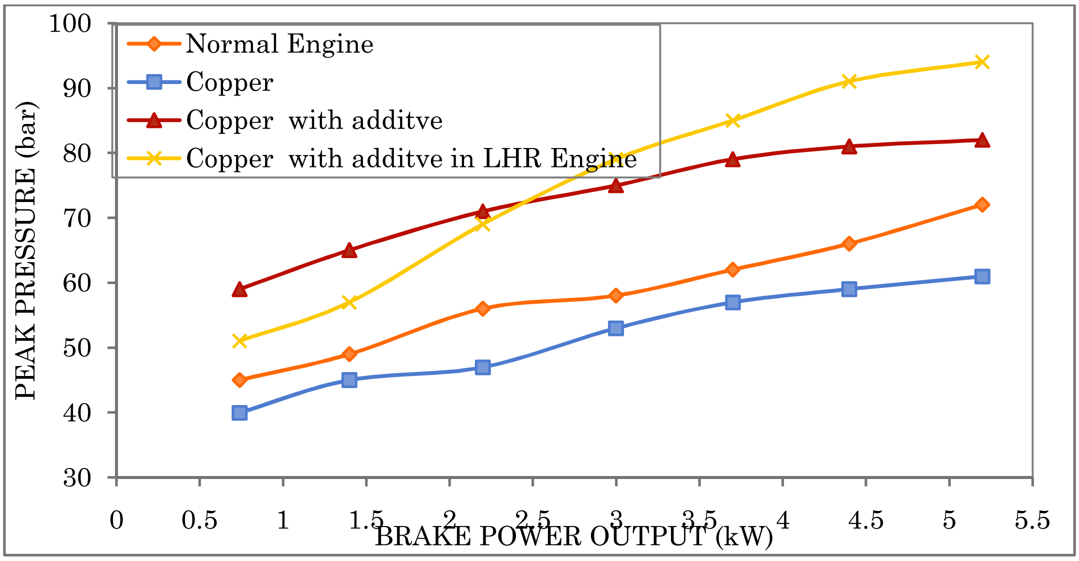

Figure14: Variation of Peak Pressure with power output for Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

Figure 14 shows the variation of peak pressure with brake power output. The peak pressure for normal GHSI engine is lower compared to the copper piston crown material GHSI with additive in LHR engine. The copper piston crown material GHSI engine with additive in LHR engine at rated load shows higher peak pressure and is about 62 bar.

4.12 Maximum Rate of Pressure Rise

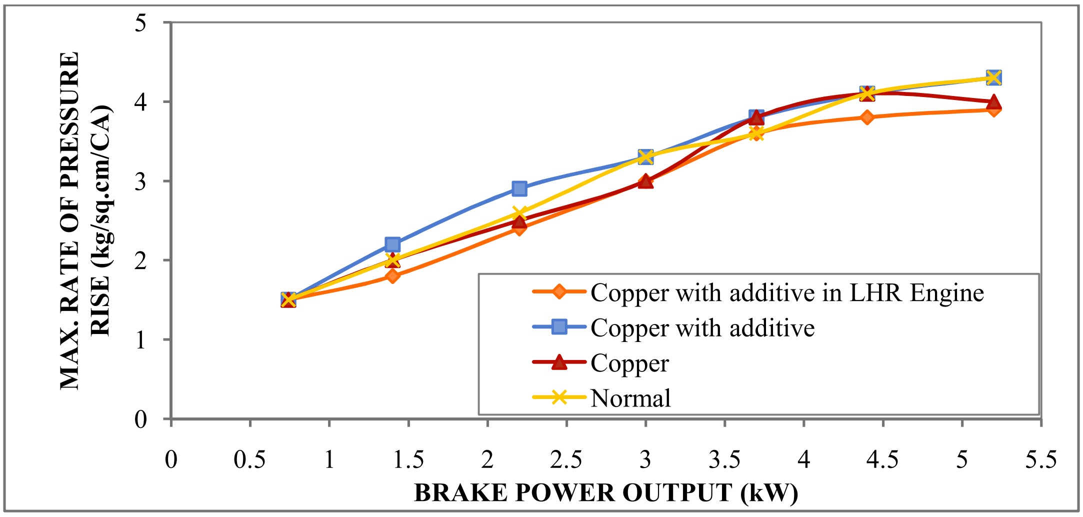

Figure15:Variation of maximum Rate of Pressure Rise with power output for Iso-amyle Nitrate Fuels in Copper GHSI -LHR Engine.

Figure 14 illustrates the variation of the maximum rate of pressure rise with brake power output. It is found that the maximum rate of pressure rise is higher for copper piston crown material GHSI with additive in LHR engine when compared with plan GHSI engine. It is the highest for copper coating GHSI engine with additive in LHR engine and is about 36% at rated load.

CONCLUSIONS

The following conclusions are drawn with Methanol operated GHSI with additive (Iso amyl nitrate) in LHR engine.

- It is found that due to better combustion the maximum percentage improvement for the copper piston crown material GHSI with additive in LHR engine over the normal engine is 6%.
- Reduced ignition delays, lower combustion duration, higher peak pressure and higher rates of pressure rise are noted for the copper piston crown material GHSI engine with additive in LHR engine.
- This must be due to the better vaporization of injected fuel in a shorter time. For copper piston crown material GHSI with additive in LHR engine, the ignition delay is lower by 3.2^0CA.
- The increase in peak pressure level is 58.5 bar, the maximum rate of pressure rise increase by 66% at rated load Hence copper piston crown material GHSI with additive (Iso amyl nitrate) in LHR engine is smoother.
- It is found that, the emission levels are lower with copper piston crown material GHSI with additive (Iso amyl nitrate) in LHR engine.
- The LHR engine indicates lower level CO emissions and is about 9%. The maximum reduction in HC level over the corresponding normal GHSI engine.

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